Trapping, focusing and sorting of microparticles through bubble streaming

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Abstract

Ultrasound-driven microbubbles rectify oscillatory motion into strong steady streaming flow [1, 2]. In this fluid dynamics video, we show size-dependent trapping, focusing and sorting of microparticles, utilizing the interaction between bubble streaming and the induced streaming around the mobile particles. This mechanism is purely passive and is selective for sizes and size differentials far smaller than any scale imposed by the device geometry.

Movie description

The video is available in High resolution and Low resolution. It consists of 5 movie segments. All movies are played at 30 frames per second. The detailed descriptions of the movies are as follows:

1. This movie shows the motion a $5\mu m$ tracing particle around an oscillating microbubble at both fast and slow time scales. The fast time scale illustrated the fast, low-amplitude oscillatory flow; at the slow time scale, the secondary steady streaming flow with closed streamlines is visible. The ultrasound driving frequency is 25.5 kHz and the amplitude is 10 V_{rms}. Movie 1(a) was captured at 95238 frames per second; movie 1(b) was captured at 30 frames per second.

2. This movie shows the size dependent characteristic trajectories of suspended particles in bubble streaming flow. The $5\mu m$ and $10\mu m$ density-matched particles are

drawn towards the oscillating bubbles due to an attractive bubble/particle interaction resulting from induced streaming. Because the particles cannot penetrate the bubbles, they are forced onto different trajectories. The movie was captured at 250 frames per second.

3. This movie shows that superimposing unidirectional Poiseuille flow destroys the symmetry of the streaming flow. The differential strength of the bubble/particle interaction now selects which particles are transported and which are trapped near the bubbles. In 3(a), $10\mu m$ particles are trapped upstream of the bubble, while $2\mu m$ and $5\mu m$ particles are carried downstream. Further upstream accumulation leads to the escape of the larger particles into narrow trajectory bundles. The movie was captured at 200 frames per second.

4. The trapping and releasing mechanism can be further exploited for focusing and sorting. This movie shows that alternating microbubbles along a microchannel focuses $10\mu m$ particles into a very narrow trajectory bundle. In 4(a), the particles remain distributed widely as the bubbles are not excited. In 4(b), the oscillating microbubbles successively relay the particles through the trapping-and-releasing mechanism. The movie was captured at 100 frames per second. In 4(c), we compare results from experiment and a simulation of the steady streaming flow based on Stokes flow singularities.

5. This movie shows that an oscillating bubble placed near a T-junction sorts particles above a certain size into one specific outlet. Optimizing ultrasound driving frequency and amplitude allows for the selection of $5\mu m$ particles to be trapped, released, and sorted over $2\mu m$ particles, which remain unsorted. This demonstrates the flexibility and tunability of this technique, which can overcome physical restrictions of the device itself. Without microbubble excitation (5a), both $5\mu m$ and $2\mu m$ particles are equally carried to the upper and lower outlets. In 5(b), upon exciting, the microbubble sorts the $5\mu m$ particles into the upper outlet. The movie was captured at 100 frames per second.

References

1. Marmottant, P., & Hilgenfeldt, S. *Nature*, **423**(6936), 153-156 (2003).

2. Marmottant, P., Raven, J. P., Gardeniers, H., Bomer, J. G., & Hilgenfeldt, S. *Journal of Fluid Mechanics*, **568**, 109-118 (2006).